

# CIRCULATION PATTERNS ASSOCIATED WITH HEAVY SNOWFALL OVER THE WESTERN UNITED STATES

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## ABSTRACT

The relationship between circulation and heavy snowfall over the western United States is studied as a means of improving operational forecasts for that region. The models developed relate occurrence of heavy snowfall in 12-hr. periods to initial circulation features and are suitable for direct use on available circulation prognoses.

## 1. INTRODUCTION

Experience at the National Meteorological Center has shown that heavy snow forecasting for the western United States is significantly more difficult than over the eastern United States. This, in part, may be due to insufficient knowledge of circulation patterns favorable to the occurrence of importantly large areas of heavy snow over this region. In view of this, and also to take advantage of the increasing accuracy of the products of numerical weather prediction, models have been developed for the western United States relating circulation features to occurrence of heavy snow in three types of synoptic situations.

## 2. PROCEDURE

Developmental data, listed in table 1, consist of all heavy snow situations (22 cases during the four snow seasons, September through May, 1963–1967) for that area of the United States west of 100°W. Heavy snow, as defined for this study, is snowfall of 4 in. or more over a minimum contiguous area of 6 square degrees of latitude (about 21,578 n.mi.<sup>2</sup>) during the specific 12-hr. periods from 0000 to 1200 GMT or 1200 to 0000 GMT. If the observed heavy snowfall overlapped the 100°W. meridian, the case was used when more than one-half of the area of heavy snow occurred west of this meridian. There were 22 cases in the four snow seasons that met all qualifications, so snowfall events of this magnitude in the western United States are relatively infrequent. Although distribution and amount of snowfall in mountainous areas are greatly dependent upon topographic features, the extensive snowfall in these cases resulted primarily from the producing capacity of effective atmospheric dynamics.

The moving grid was used in relating heavy snowfall to synoptic features in a manner similar to Jorgensen [1] and Fawcett and Saylor [2]. Previous studies by Goree and Younkin [3] and Hanks et al. [4] had shown a systematic relationship of heavy snowfall to 500-mb. vorticity maxima; so where possible, the initial 500-mb. vorticity maximum<sup>1</sup> and its direction of movement during the subsequent 12 hr. served as the anchoring coordinates in obtaining model distributions of various parameters.

TABLE 1.—*Western United States snowstorms (1963–1967 snow seasons) with heavy snowfall areas exceeding 6.0 square degrees of latitude. Date and time are as of the beginning of the 12-hr. snowfall period. Values of associated 500-mb. vorticity maximum ("digging" and "coming out" cases) are in units of  $10^{-5}$  sec.<sup>-1</sup>*

Case No.	Date	Time (GMT)	Vorticity Maximum	Area of Heavy Snow	Type
1.....	3- 2-64	1200	17.1	6.1	Digging
2.....	3- 3-64	0000	18.4	10.5	Digging
3.....	11-14-64	1200	18.0	8.8	Coming Out
4.....	12-19-64	1200		8.0*	Pacific NW
5.....	12-21-64	1200		12.0	Pacific NW
6.....	1-23-65	1200		9.4*	Pacific NW
7.....	1-24-65	0000		8.4*	Pacific NW
8.....	2- 7-65	0000	22.1	7.1	Coming Out
9.....	9-16-65	1200	19.4	18.2	Digging
10.....	2-24-65	0000		8.7*	Pacific NW
11.....	12-27-65	1200		16.8*	Pacific NW
12.....	2- 9-66	0000	16.3	6.1	Coming Out
13.....	3- 2-66	0000	16.4	10.5	Digging
14.....	3- 2-66	1200	13.0	10.2	Coming Out
15.....	3- 3-66	0000	17.1	26.2	Coming Out
16.....	3-22-66	1200	20.4	6.6	Digging
17.....	4-19-66	0000	16.5	21.7	Digging
18.....	11- 8-66	1200	18.0	6.6	Digging
19.....	12- 6-66	1200	13.4	6.3	Digging
20.....	12-27-66	0000	18.8	6.9	Digging
21.....	4-30-67	1200	17.5	14.3	Coming Out
22.....	5- 1-67	0000	19.5	12.4	Coming Out

\*South of the Canadian border.

The storms first were classified as to their "digging" or "coming out" characteristics. A "digging" storm was characterized by a vorticity maximum moving south of east during the 12-hr. snowfall period. In these instances the short waves "dig" into the long wave trough position or "dig" out a new long wave trough position. Figures 1 and 2 show composite circulation features as related to 12-hr. heavy snowfall for these storms (nine cases).

A "coming out" storm was one in which the vorticity maximum was moving north of east. In these instances the short waves move out from the long wave trough position. When two vorticity maxima were involved in relatively close juxtaposition in the same large-scale trough, the advance center was used as it maintained a more normal relationship to the snowfall area. Figures 3 and 4 show composite circulation features as related to 12-hr. heavy snowfall for "coming out" storms (seven cases).

<sup>1</sup> The 500-mb. vorticity analyses were obtained from the NWP barotropic analyses with data cutoff at approximately 1 hr. and 30 min. after regular upper air observation time.

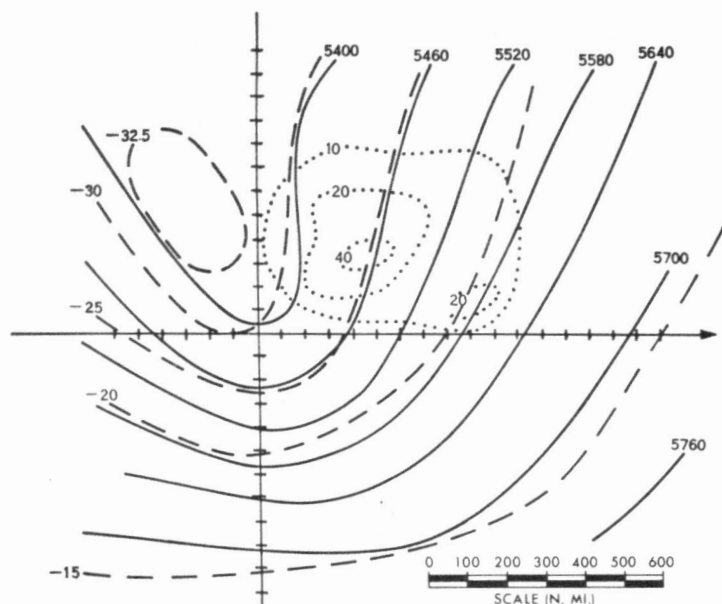


FIGURE 1.—“Digging” type. Percentage frequency of occurrence of heavy snow (dotted lines), and composite initial 500-mb. height (gp.m., solid lines) and temperature ( $^{\circ}\text{C}$ ., dashed lines). Origin is at initial position of vorticity maximum with horizontal coordinate pointing in the direction of its movement during the following 12 hr. Average direction and speed of movement toward  $121^{\circ}$  at 27 kt. Tick marks on coordinates represent degrees of latitude.

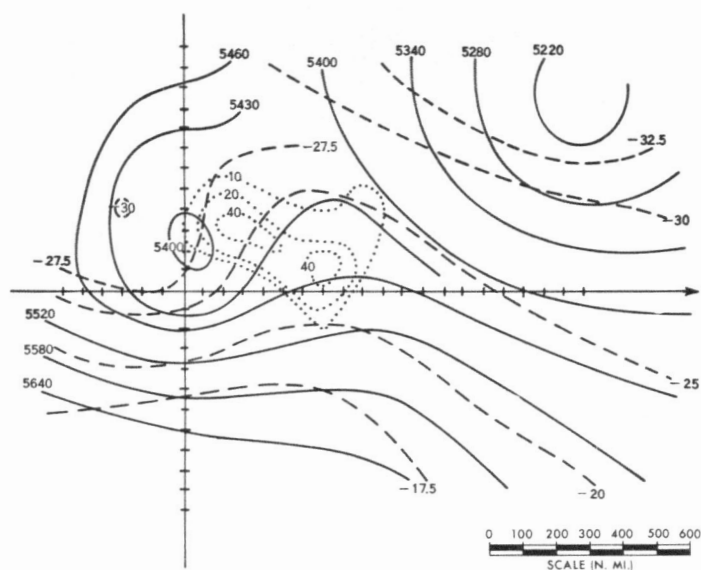


FIGURE 3.—“Coming out” type. Percentage frequency of occurrence of heavy snow (dotted lines), and composite initial 500-mb. height (gp.m., solid lines) and temperature ( $^{\circ}\text{C}$ ., dashed lines). Orientation is the same as in figure 1. Average direction and speed of movement of vorticity maxima, toward  $36^{\circ}$  at 22 kt. Tick marks represent degrees of latitude.

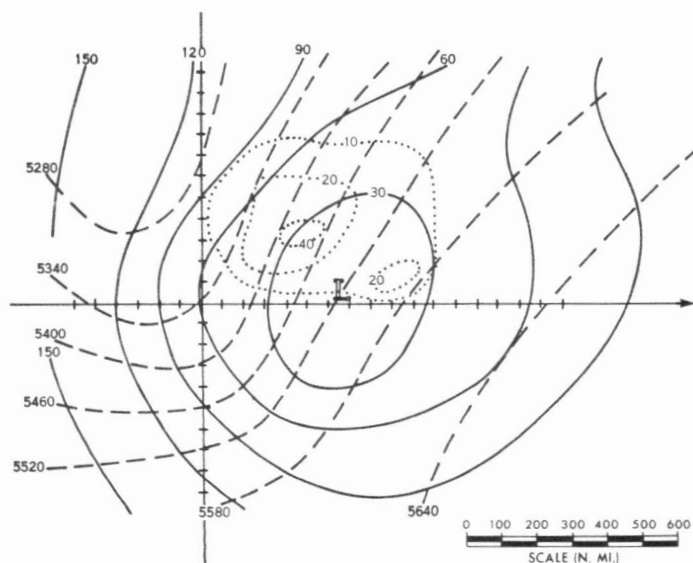


FIGURE 2.—“Digging” type. Percentage frequency of occurrence of heavy snow (dotted lines), and composite initial 1000-500-mb. thickness (gp.m., dashed lines) and 1000-mb. height (gp.m., solid lines) obtained by subtracting composite thickness from composite 500-mb. height. Orientation is the same as in figure 1. Tick marks on coordinates represent degrees of latitude.

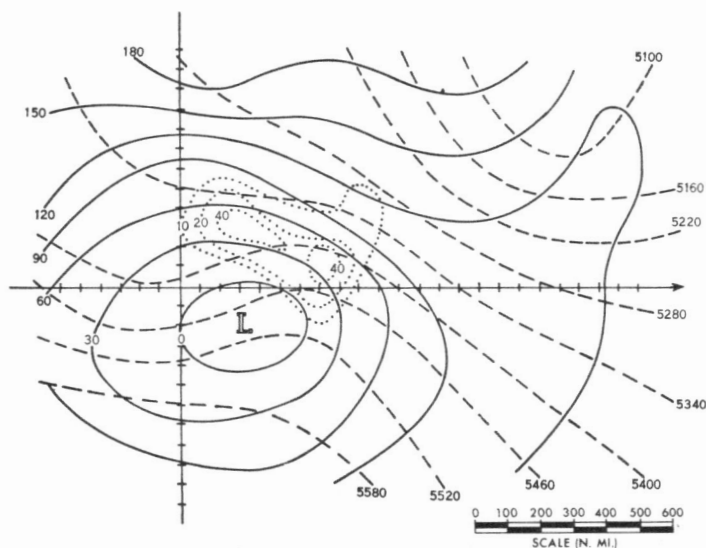


FIGURE 4.—“Coming out” type. Percentage frequency of occurrence of heavy snow (dotted lines), and composite initial 1000-500-mb. thickness (gp.m., dashed lines) and 1000-mb. height (gp.m., solid lines) obtained by subtracting composite thickness from composite 500-mb. height. Orientation is the same as in figure 1. Tick marks represent degrees of latitude.

There were six cases where the vorticity analyses in the eastern Pacific Ocean were not sufficiently accurate to specifically locate the vorticity maxima or determine their direction of movement. Therefore, since relatively accurate positions of vorticity maxima were not obtainable it was necessary to abandon the procedure of using

vorticity maxima in locating the frame of reference. Instead, in these cases, subjectively determined centroids of the observed heavy snow areas and the north azimuth served to anchor the coordinates in obtaining composite models. All of these cases were in the Pacific Northwest, west of the Continental Divide with heavy snowfall predominantly in the State of Washington, and, therefore, classified as “Pacific Northwest” storms. Figures 5 and 6 show composite circulation features as related to 12-hr. heavy snowfall for this class. The use of the Pacific

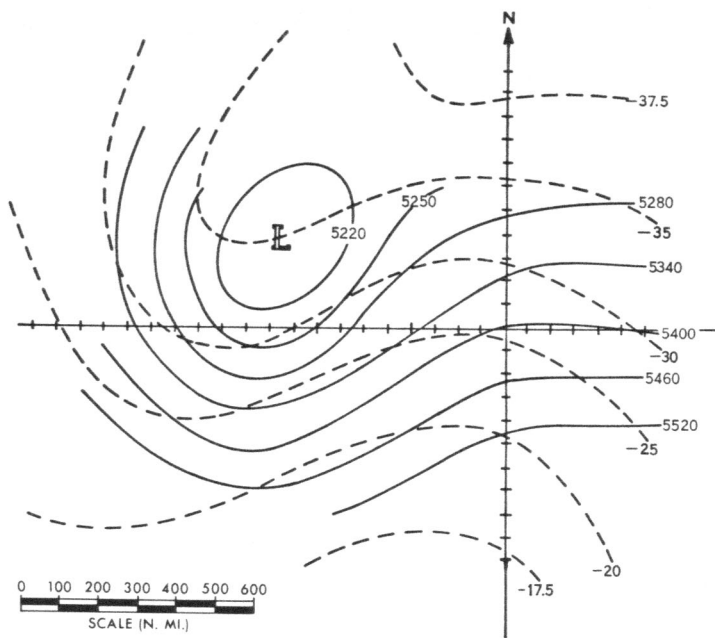


FIGURE 5.—“Pacific Northwest” type. Composite initial 500-mb. height (gp.m., solid lines) and temperature ( $^{\circ}\text{C.}$ , dashed lines). The centroid of observed heavy snow is considered the origin. Tick marks represent degrees of latitude.

Northwest models in forecasting differs from the use of the models for the other two types. In this instance, the model is fitted—as best possible—to the forecast circulation pattern (with special consideration to trough and ridge lines and careful regard to thermal requirements for snow); then the origin of the coordinates will point out the region where heavy snow is most likely to occur.

### 3. DISCUSSION OF RELATIONSHIPS

Figures 1 through 6 indicate certain favored locations for occurrence of heavy snowfall in relation to the various parameters given. In all three types the great predominance of heavy snowfall occurred between the  $-20^{\circ}\text{C.}$  and  $-30^{\circ}\text{C.}$  500-mb. isotherms. However, in exception to this it should be pointed out to the practicing meteorologist that there were two digging cases with heavy snowfall mainly within the  $-15^{\circ}\text{C.}$  to  $-20^{\circ}\text{C.}$  isotherm channel. Heavy snowfall in “digging” and “coming out” situations were quite similar in relationship to the initial position of the vorticity maxima and the directions of movement during the subsequent 12 hr. Also, in both types heavy snowfall occurred mainly between the 5340-gp.m. and 5460-gp.m. 1000–500-mb. thickness contours. Interestingly enough, a composite construction (contour heights and percentage frequency of heavy snow from figures 2 and 4 after appropriate reorientation of abscissae) shows the distribution of heavy snow frequency in relation to 500-mb. pattern to be markedly similar to that found for heavier precipitation by Klein et al. [5] for 500-mb. Lows of more than weak intensity.

“Pacific Northwest” situations were distinctively different from the other western types in several respects.

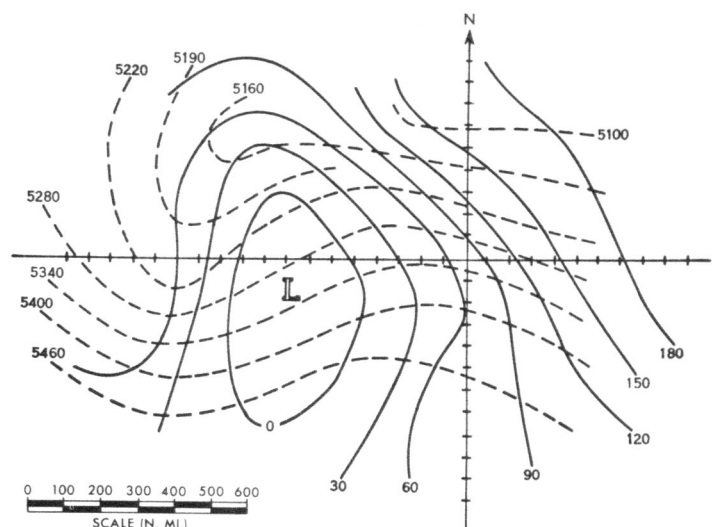


FIGURE 6.—“Pacific Northwest” type. Composite initial 1000–500-mb. thickness (gp.m., dashed lines) and 1000-mb. height (gp.m., solid lines) obtained by subtracting composite thickness from composite 500-mb. height. The centroid of observed heavy snow is considered the origin. Tick marks represent degrees of latitude.

First, strong warm advection is present in the troposphere over the area of observed heavy snow. Not only is this indicated by the marked advection of thickness by the 1000-mb. height contours (fig. 6), but also the noticeable advection of the 500-mb. isotherms by the 500-mb. contours (fig. 5). Second, the 500-mb. trough position (fig. 5) is some  $10^{\circ}$  of lat. distance from the centered heavy snowfall. Third, the predominance of heavy snow occurred between the 5280- and 5400-gp.m. 1000–500-mb. thickness contours (fig. 6), some 60 gp.m. less than in the other two types.

### ACKNOWLEDGMENTS

I wish to thank Mr. Harlan K. Saylor and Edwin B. Fawcett of the Analysis and Forecast Division of NMC for helpful suggestions, also, Mr. Eugene Brown and Jane Violet for preparation of figures.

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